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TECHNICAL REPORT
66-39-CM

BALLISTIC RESISTANCE OF NEEDLE-PUNCHED NYLON FELTS

by

Richard C. Keith

The Felters Company
Boston, Massachusetts

Contract No. DA 19-129-AMC-204 (N)

May 1966

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing and Organic Materials Division
TS-137

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FOREWORD

At low areal densities (6 oz/ft^2), needle-punched felt exhibits relatively high ballistic resistance. It is approximately 80 percent as effective as the standard ballistic-resistant nylon armor duck that weighs three times as much. At higher areal densities (18 oz/ft^2), felt and duck fabrics are about equal in ballistic resistance. Because of its superior ballistic resistance at low weights, needle-punched nylon felt is an important material to be considered for personnel armor.

The work covered by this report was performed by The Felters Company under U. S. Army Contract DA-19-129-AMC-204(N). It involves a study of construction and processing techniques for an optimum needle-punched nylon felt that would be reproducible at reasonable cost by industry.

The contract was initiated under Project 1C024401A329-02 and was administered under the direction of the Textile Engineering and Finishing Branch of the Clothing and Organic Materials Division of the U. S. Army Natick Laboratories, with Mr. E. A. Snell acting as Project Officer and Mr. George Groh as Alternate Project Officer.

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ABSTRACT

Felts made from high tenacity nylon 6,6 (industrial quality), bright, 6-denier filament, three-inch staple, crimpset fiber were found to be the most satisfactory in ballistic resistance, uniformity, and ease of processing among the group studied. Batts that were cross-laid proved to be superior to the parallel-laid batts and equal to a combination of straight- and cross-laid batts. The best felt, from the standpoint of both ballistic resistance and dimensional stability, was produced by needling 4-ounce batts alternately on each side, with 277 penetrations per square inch and a half-inch needle penetration, followed by flat-bed pressing (using 0.29-in spacer bars at 310°F for 2-1/2 min) to attain the desired thickness.

Producer's virgin waste of the same high tenacity nylon 6,6 appeared to be promising although the test results were inconclusive. These and other fibers, also various processing methods and treatments, are discussed.

BALLISTIC RESISTANCE OF NEEDLE-PUNCHED NYLON FELTS

1. Purpose and Scope

Previous studies conducted by the U. S. Army Natick Laboratories on ballistic-resistant needle-punched felts, using nylon, polyester, acrylic, modacrylic, polypropylene, acetate, and viscose fibers, revealed that felts made of nylon fiber have the highest ballistic resistance. Therefore, the efforts in this program were confined largely to nylon.

The objective of the program was the establishment of parameters for the design and processing of a nylon felt having optimum ballistic resistance at a weight of 54 oz/yd^2 and a thickness of .330 inch. The factors investigated were the raw stock, batt formation, needling, pressing and stabilizing, and chemical treatments. To achieve an orderly development in these areas, the work was divided into the following five phases:

Phase I

a. Batt forming techniques
b. Needling and pressing methods

Phase II

a. Needling and pressing methods
b. Raw stock blends

Phase III

a. Needling and pressing methods
b. Raw stock blends
c. Chemical and stabilizing treatments

Phase IV

Chemical and stabilizing treatments

Phase V

Confirmatory manufacturing and testing of optimum felt developed

The felts made are identified in this report by phase number.

Throughout the effort, a primary consideration was the design and manufacture of an optimum felt that would be practicably reproducible at reasonable cost on conventional production equipment.

Ballistic resistance (V_{50}) tests were conducted in accordance with Military Standard MIL-STD-662 "Ballistic Acceptance Test Method for Personal Armor" (15 June 1964), by Victory Plastics Company, Hudson, Massachusetts.

2. Summary of Results

A. Raw Stock Of the nylon felts previously evaluated by the U. S. Army Natick Laboratories, there were two that were highest in V_{50} ballistic value: one made entirely of high-tenacity tire cord, 6 dpf, bright, no crimp, cut 3 inches; and one made with two-thirds of this fiber and one-third of normal-tenacity nylon, 3 dpf, semi-dull, crimpset, cut 2 inches. Since manufacturing experience has indicated that the blend processes into more manageable webs of acceptable and controlled quality, a similar blend was used for the initial phase of this program, i.e., 65% of the high tenacity and 35% of the normal tenacity. This was used for all eleven of the Phase 1 felts (1.1 - 1.11).

In Phase II, three other types of raw stocks were tried. A 100% crimpset, high-tenacity nylon, 6 dpf, bright, cut 3 inches was used for eight felts (2.1 through 2.8) as it was thought this would increase ballistic resistance through greater fiber strength and fiber disorientation. Furthermore, it was believed this stock would provide a greater uniformity of web and ease of processing, both of which are normally associated with 100% crimped blends, than the Phase I blend. All of these improvements were realized (App. I), therefore this was the fiber used in Phases IV and V and for the experiments in web formation, needling, and chemical treatments of Phase III.

One Phase II felt (2.9) was produced from 6 dpf, high tenacity, bright, crimpset type 6,6 producer's waste, cut 3 inches. The purpose of using this fiber was, of course, to determine whether or not lower-cost raw stock could be used in ballistic felts. The V_{50} results obtained on this felt versus those of a control (2.1) were not conclusive but were encouraging.

The third Phase II felt (2.10) and one Phase III felt (3.2) were made with a blend of 90% crimpset, high-tenacity nylon, 6 dpf, bright, cut 3 inches; and 10% 6 dpf, 2-inch, crimped, polypropylene. It was hoped that, during pressing, the polypropylene, being thermoplastic, would flow and cause the nylon fibers to adhere to each other. This would increase dimensional stability and decrease the mobility of the nylon fibers under impact. However, neither of these felts was ballistically acceptable because fiber slippage was too greatly reduced.

In Phase III, two felts (3.3 and 3.4) were made from 100% crimpset nylon similar to that used in Phase II but cut 2 inches. This was done to improve the fiber condition in random-laid batts, as there was too much fiber breakage when the batts were formed from 3-inch staple. Although the desired reduction in breakage was realized, these felts were not ballistically equal to those made with 3-inch staple (see Appendix II).

B. <u>Batt Formation</u> Previous developmental studies had employed parallel- or straight-laid batts primarily, although one multi-directional web construction had been used and some ballistic felts had been made commercially with cross-laid batts While the non-parallel types appeared to be superior to the parallel, in this program it was decided to compare all four types of batt formation: parallel, cross, combination parallel/cross, and random. This was done in Phases I and II (App. I).

The parallel, cross, and combination batts were all produced to a weight of 4 oz/yd^2 ($\pm$ 10%) on a conventional, single cylinder, woolen card equipped with a double feed box and breast section. The random-laid batts, also weighing 4 oz/yd^2, were formed on a Curlator Corporation Rando-Webber.* For the cross-laid batts, the weight was attained either by lapping a card web weighing 1-1/3 oz/yd^2 three times, using an apex angle of 17°, or by lapping a 2-oz/yd^2 card web twice, using an apex angle of 33° 14'.

The parallel, cross, and combination batts all processed well. The random batts made with 65% 6 dpf and 35% 3 dpf staple (1.11) were found to be too weak to carry through the needling operation unsupported and therefore one parallel batt was needled and used as a base onto which the random batts were laid and needled. The other random batts used had greater strength and could be handled normally.

In Phase I, it was indicated that the random batt arrangement might produce the best ballistic-resistant characteristics if longer fibers could be processed. The cross-laid, regardless of apex angle (17° or 33°), appeared to be superior, ballistically, to the other batt types particularly when the 100% crimped fiber stocks were used (Phase II), as the inherently disoriented nature of these added to the general fiber disarray.

C. <u>Needling</u> A James Hunter Fiberlocker Model 16, with standard needle boards, was used with the regular 18 x 32 x 3½, RB no-kick-up barb-type needles. Excluding the exceptions noted (2.5, 2.8, 3.5), the needling concentration for all felts was 277 penetrations per square inch per needling, with a penetration of one-half inch. The stripper plate setting was five-eighths inch from the bed on the delivery side, with a three-quarter inch increase on the feed side. Penetrations per minute were arbitrarily maintained at 300 for ease in handling the short lengths manufactured.

*Courtesy of Curlator Corp., East Rochester, New York

To attain maximum needling productivity, all the batts except those noted in Phase I and Phase III were needled consecutively. (See App III.) That is, a 4-oz batt was passed through the needles and then returned to the feed end of the unit where another batt was applied to the opposite side and the combination passed through the needles. This process of adding one batt at a time was repeated to build up the desired total weight. After all the batts had been assembled, the density of the felt and the fiber orientation in the vertical plane were controlled by additional needling as required. The combination parallel/cross batts were needled in such a sequence that they appeared as alternate layers in the finished felt.

1) <u>Pre-Needling and Laminating</u>. Because, productively, pre-needling a series of 4-oz batts and then laminating them by re-needling as necessary to achieve the required density is nearly as efficient as consecutive needling, one felt (3.6) was made using this generally accepted technique. Although this method proved to be economically and ballistically practical, it was found to pose a quality control problem; weight control was highly problematical because the degree of stretch or shrinkage in length and width during needling could not be reasonably predicted from one time of manufacture to another. Under this method, it is impractical to add more weight if the felt is found to be too light and it is impossible to deduct weight if it is found to be too heavy.

2) <u>Needling Penetration & Concentration</u>

Phase I was devoted to establishing the parameters of needling intensity necessary to construct felts of acceptable ballistic resistance. To this end, batts in the various formations under consideration were needled consecutively as follows: one per pass, in sequential lamination; two per pass; and four per pass. Part of the investigation of needling penetration was carried over into Phase II. Test results indicated that the original concept of needling 4-oz batts of any formation on a consecutive basis produces the best ballistic resistance and dimensional stability.

A pattern of decreasing needle penetration for felt 2.5 was adopted to maintain a loftier character and thus perhaps increase the kinetic energy absorption by increasing fiber slippage. Needle penetration on the first two needling passes was 5/8-inch; on the next two, 1/2-inch; on the following two, 3/8-inch; and on the balance, 1/4-inch. This decreasing penetration approach was found to be deleterious; therefore, in Phase III, a reverse technique was used for felt 3.5. A 1/4-inch penetration was used for the first two passes, and 3/8-inch for the next two. This approach produced no appreciable benefit. It was therefore decided to simplify manufacture by adopting the original 1/2-inch penetration throughout the remaining production of felts.

In making felt 2.8, a lesser needling concentration per square inch was used on each pass. Again, the thought was to improve fiber mobility and hence reduce shearing and improve kinetic energy absorption. However, this change was found to be impractical for, given the same number of machine passes, the lesser concentration produced a too lofty and dimensionally unstable felt. The subsequent additional passes required to correct this condition apparently negated any ballistic resistance advantage.

D. Finishing

1) <u>Pressing</u> Because of the superior quality control which can be achieved with a flat-bed hydraulic press, this was the type used for all the felts except those needled to the required thickness of .330-inch (1.1 and 1.5). Phase I felts were pressed at 310°F for 2-1/2 minutes, using 0.290-inch spacer bars. Phase II felts were pressed at the same temperature and with the same spacing but the cycle time was increased from 2-1/2 to 6 minutes to insure the stability of the felts made of 100% crimped fiber. For all the other felts produced in the program, the cycle time was increased to 10 minutes without, however, any advantage other than the certainty of complete heat penetration.

   In addition to the flat-bed press, rotary pressing was also tried. Using the minimum practical operating gap for this material (0.100 inch), a bed temperature of 260°F, a drum temperature of 340°-350°F, and a speed of 6 ypm, the minimum thickness attainable was 0.380-inch.

2) Stabilizing After pressing, all of the felts that were sufficiently needled to have reasonable ballistic resistance were found to have acceptable dimensional stability for their end use. Even after being wetted out in room-temperature water and allowed to air-dry, they showed no significant dimensional changes. The stabilizing treatments employed, therefore, were used only because it was thought they might improve ballistic resistance. High-temperature pressing at 393°F, using 0.290-inch spacer bars and a 10-minute cycle, was tried (4.2) to determine the effect of heat setting the fibers in a compressed condition. Likewise, heat setting in an oven at 400°F for 2-1/2 minutes and then pressing at 310°F was tried (4.4) to learn the effect of setting the fibers in their needled configuration. Neither of these treatments produced any ballistic advantage.

   One felt (4.3) was semi-decated for a 10-minute steam cycle, with no vacuum cycle, and then pressed at 310°F to evaluate heat setting with moisture and to deluster the fibers somewhat to increase fiber-to-fiber friction. This treatment may have improved the ballistic resistance, but verifying tests are required before a definite conclusion can be reached.

E. Treating Previously a limited amount of work on water-repellant treatments using "Quilon"*had revealed that, for the concentrations used, there is a loss in ballistic resistance of approximately 12%. In this program, therefore, it was determined to establish parameters for the strength and application of this treatment as an initial step in reducing water absorption and increasing ballistic resistance. An arbitrary maximum of 25% absorption was sought.

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* A treatment material supplied by E. I. du Pont de Nemours & Co.

As Table I shows, the Quilon treatment was found to be ineffective in reducing water absorption (felts 3.7 to 3.10) because the chemical migrated to the surface during drying. It was, of course, excellent in providing water repellency, for the same reason. Ballistically, the treatment had the anticipated effect of lowering the V_{50} values as its intensity increased.

TABLE I

WATER ABSORPTION AFTER TREATMENT WITH QUILON

SAMPLE	TREATMENT	PICKUP (%)	V_{50}
3.1	Untreated	324	1091
3.7	10% surface application	392	1066
3.8	10% saturation application	292	962
3.9	5% surface application	357	1063
3.10	5% saturation application	330	987

Obviously, the application of Quilon alone is inadequate. A treatment is needed to more effectually block the voids in the felts and to introduce a frictional agent to counteract the lubricity imparted to the fibers by the Quilon. Therefore the following two-bath treatments were applied to felts 4.5 through 4.8:

4.5	5% SOD soap*, 10% Quilon
4.6	5% rosin size**, 10% Quilon
4.7	5% fig soap***, 10% Quilon
4.8	10% SOD, 25% zirconium salts****

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*A product of Original Bradford Soap Works, Inc., with the proprietary name of Bradsyn SOD

**An American Cyanamid Co. product called Cyanatex rosin size KM509

***A product of Laurel Soap Co., Inc., known as Fig Soap T5

****An American Cyanamid Co. product called Paramul DC-2

Approximately one yard of felt, 58" wide, was treated in these solutions by padding on the Wringmaster, using two runs at 80 pounds pressure in the first bath and one run at 80 and one run at 50 pounds pressure in the second bath. There was a deliberate delay of one hour between impregnation and drying. Static water absorption tests (AATCC method) made before and after pressing gave the averaged results shown in Table II.

The results from two samples, one cut from the center of the leading edge of each piece, and one cut from one side of each piece were averaged. Obviously, none of the treatments achieved the 25% maximum desired.

TABLE II

WATER ABSORPTION AFTER COMBINATION TREATMENTS

Sample	AVERAGE PICKUP (%) Before Pressing	After Pressing
4.5	53.0	36.6
4.6	149.1	132.0
4.7	Over 150.0	67.8
4.8	54.8	66.2

After the static test, the samples were redried at 255°F, conditioned, then weighed and immersed for 20 minutes at an average hydrostatic head of 3.5 inches, removed and allowed to drain for 5 minutes in a vertical position, then reweighed and the percentage of water pickup again calculated. Table III gives the results of the two test methods.

It would seem from the few tests made that the 5-minute drain method would more nearly show actual results in the field than the AATCC method although reproducibility would probably not be as good. "Fuzziness" of the surface apparently has a marked effect on the results obtained by the 5-minute drain method; a fuzzier surface mechanically holds more water and does not permit it to drain off immediately.

TABLE III

TABULATED RESULTS OF STATIC WATER ABSORPTION USING STANDARD TEST METHOD AATCC 21-1961 vs. 5-MIN. DRAIN TEST

Sample	Results of AATCC Static Test		5-Min. Drain Test		Pickup Difference Between Test Results (%)
4.5 Center	Wt. before	8.230	Wt. before	8.233	
	Wt. after	11.563	Wt. after	13.601	
	Difference	3.333	Difference	5.368	
	Pickup (%)	40.5	Pickup (%)	65.4	+ 24.9
4.5 Edge	Wt. before	8.966	Wt. before	8.970	
	Wt. after	11.900	Wt. after	19.477	
	Difference	2.934	Difference	10.507	
	Pickup (%)	32.7	Pickup (%)	117.3	+ 84.6
4.6 Center	Wt. before	10.256	Wt. before	10.246	
	Wt. after	24.511	Wt. after	17.659	
	Difference	14.255	Difference	7.413	
	Pickup (%)	139.0	Pickup (%)	72.4	- 66.6
4.6 Edge	Wt. before	10.032	Wt. before	10.030	
	Wt. after	22.555	Wt. after	21.661	
	Difference	12.523	Difference	11.631	
	Pickup (%)	125.0	Pickup (%)	116.0	- 9.0
4.7 Center	Wt. before	9.516	Wt. before	9.510	
	Wt. after	16.963	Wt. after	20.224	
	Difference	7.447	Difference	10.714	
	Pickup (%)	78.1	Pickup (%)	112.8	+ 34.7
4.7 Edge	Wt. before	9.842	Wt. before	9.841	
	Wt. after	15.500	Wt. after	18.937	
	Difference	5.658	Difference	9.096	
	Pickup (%)	57.5	Pickup (%)	92.5	+ 35.0
4.8 Center	Wt. before	9.966	Wt. before	9.953	
	Wt. after	16.752	Wt. after	18.733	
	Difference	6.786	Difference	8.780	
	Pickup (%)	68.1	Pickup (%)	88.2	+ 20.1
4.8 Edge	Wt. before	10.964	Wt. before	10.918	
	Wt. after	18.005	Wt. after	19.524	
	Difference	7.041	Difference	8.606	
	Pickup (%)	64.2	Pickup (%)	78.8	+ 14.6

Other two-bath repellent treatments were also investigated, but only on a laboratory basis. All were found to be unsatisfactory. The method of application was essentially the same as that used on samples 4.5 through 4.8. These treatments were as follows:

10%	Zirconium salts sol. containing 1% aluminum formate	
5%	Fig soap, 5% Zr. salts sol.	(2-bath)
5%	Fig soap, 5% Quilon sol.	(2-bath)
5%	Rosin size, 5% Zr. salts sol.	(2-bath)
10%	SOD soap, 10% Quilon	(2-bath)
10%	Rosin size, 10% Quilon	(2-bath)
5%	SOD, 5% rosin, 10% Quilon	(2-bath)
10%	SOD, 15% Zr. salts	(2-bath)
10%	Rosin size, 15% Zr salts	(2-bath)
5%	SOD, 5% rosin size, 15% Zr. salts	(2-bath)
5%	SOD, 20% Zr. salts	(2-bath)
10%	Sylmer 72* and catalyst	
5%	Sylmer 72* and catalyst	

Fifty square yards of felt 5.1 were manufactured in Phase V and delivered to U. S. Army Natick Laboratories. This was a duplicate of the felt (2.4) which exhibited the highest V_{50} in this study (1118 ft/sec). In Phase V, felt 2.4 was again tested for confirmatory purposes and for a direct comparison with felt 5.1. A V_{50} of 1108 confirmed the earlier Phase II test results; however, felt 5.1 appeared to be marginally inferior, with a V_{50} of 1069 ft/sec. The difference between the two (39 ft/sec) may not be significant and requires additional V_{50} tests to be conclusive.

A sample of the same felt (5.1) was semi-decated (5.2); also a sample was scoured and then semi-decated. It was thought that these treatments might prove beneficial; however, in ballistic resistance no improvement was attained.

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* A Dow Corning Corporation product

F. Elongation under Load versus Ballistic Acceptance

Correlation of standard felt tests with ballistic resistance (V_{50}) were studied in Phase V. Only one of the tests, as established by the American Society for Testing Materials under designation D461 and as revised in 1959, was found to give results that might have some rank correlation with ballistic resistance. This was the test for elongation under load. Since such tests measure fiber entanglement and array, the correlation may be valid.

Table IV gives the elongation and V_{50} values for selected cross-laid felts. Many similar felts will have to be tested, with account being taken of variations in such other factors as fiber length and crimp, before the relationship can be established.

TABLE IV

V_{50} VALUES VS ELONGATIONS OF SELECTED CROSS-LAID FELTS

	Elongation* (%)		
Sample	Length	Width	V_{50}
2.9	73	50	1003
3.3	73	40	1040
3.1	77	37	1091
4.3	98	62	1083
3.6	97	53	1104
2.4	119	48	1117

* Instantaneous elongation of a 2-inch strip at 160-lb load with 3 inches between jaws.

3. Conclusions

Raw Stock Of the raw stock investigated, the 100% high-tenacity nylon, 6 dpf, bright, crimpset, cut 3 inches, was definitely superior in all respects. The same fiber without crimp might be as good, ballistically, but in uniformity of quality and facility of processing it was not as satisfactory.

Any blend containing thermoplastic fibers that are subsequently bonded to nylon fibers in the finished felt produces too boardy a felt and one that is too restrictive of fiber movement for good ballistic resistance.

Producer's waste nylon of the same description as virgin staple is as good, ballistically as the virgin staple providing the strength, elongation, and surface characteristics are the same.

Web Formation Although it was strongly indicated that random-laid batts would produce felts with the highest ballistic resistance if they could be formed from an equally long staple, cross-laid batts using an apex angle of 17° or over will closely approach the same degree of resistance, particularly if made from 100% crimpset fibers.

Combination parallel/cross-laid batts were superior to the parallel-laid, which were the poorest, but not consistently better than the cross-laid to warrant the additional manufacturing problems involved, especially when crimpset fiber blends were used.

Needling With the needling equipment and needles used, machine settings of 277 1/2-inch penetrations per square inch per pass were the most effective on the raw stock investigated. The consecutive or additive method of needling batts was ballistically equal to and productively superior to that of pre-needling and laminating the batts.

With the above machine settings, the 4-oz batts will approach the optimum weight. Since the most effective thickness after needling and before finishing is in the 0.5- to 0.6-inch range, heavier or lighter batts require either too much or too little needling and thus are ballistically poorer.

Pressing Within the contractor's plant, hydraulic flat bed pressing proved to be the only satisfactory means of obtaining the necessary compression of felts needled to from 0.5 to 0.6 inch. Firms using other equipment might, of course, arrive at equal results in a different manner.

Stabilizing None of the elevated-temperature heat settings by the methods investigated appreciably improved ballistic resistance. However, it is possible that delustering the nylon fiber by steam treating, as in semi-decating, might be of value.

Treating None of the waterproofing treatments applied was ballistically acceptable. They either lubricated the fibers too much or loaded the felt so that it became boardy and too restrictive of fiber movement. It appears that the degree and type of impregnation necessary to achieve minimum water absorption in this type felt is inconsistent with and opposed to ballistic resistance requirements.

Correlation Testing No direct correlation was established between the results of ballistic and standard felt tests; however, some correlation might be found upon more extensive investigation.

4. Specification Requirements

Based on The Felters Company's experience with the felts manufactured for this study and also on other experience in manufacturing similar constructions, the following suggestions appear reasonable for establishing an acceptable quality level that is not unduly restrictive:

Construction The felt shall be a needle-punched construction made of nylon 6,6 (industrial quality), high tenacity, bright, 6 dpf, cut to 3-inch staple, and crimpset. Regenerated or reprocessed nylon should not be used. The color should be natural, the weight 51 (+ 3) oz/yd^2, and the thickness 0.33 ($\pm$ 0.03) inch. The width should be based on economy of felt manufacture and cutting. Breaking strength and splitting resistance tests are not specified since they appear to be meaningless. Any felt meeting reasonable ballistic resistance requirements must possess adequate strength.

Defects The specification should provide for such obvious defects as holes, tears, wrinkles, and oil stains, and also for the detection and removal of broken needles.

Length of Rolls The length of roll established should be based on the tolerable bulk and weight for handling and on cutting efficiency. It is suggested that a provision be made in the specification for an acceptable percentage of short pieces, the minimum length of which would depend on the patterns involved.

Ballistic Resistance (V_{50}) Because of the limited experience of The Felters Company with ballistic resistance tests, an acceptable V_{50} value for a needle-punched nylon felt of approximately 51 oz/yd^2 and 0.33-inch thick has not been suggested. It would be more appropriate for U. S. Army Natick Laboratories to establish acceptable limits based on their evaluation of the results of this and previous studies on ballistic-resistant felts and other materials. However, at this time The Felters Company would be receptive to any invitation for bids for felt, similar to those made during this study, that require a V_{50} of from 1000 to 1050 ft/sec.

5. Recommendations for Future Study

It would be of interest to manufacture for evaluation a further series of felts with the following stocks, constructions, and treatments:

a. Longer staple, 100% high-tenacity, 6 dpf, bright, crimpset nylon. Suggested lengths: 4½ and 6 inches.

b. A blend of nylon of the above description cut 4½ inches, with 2- to 3-inch steel fibers.

c. One hundred per cent high-tenacity nylon, stretched-to-break rather than cut-to-staple. The greater tenacity of this fiber would be expected to increase ballistic resistance.

d. Plied layers of lighter felts, preferably with varying densities, with the higher-density felts at the back of the composition.

e. A two-layer felt or two plies of felt in which one layer is made of fibers having greater elongation than the other. The two 100% nylon stocks described above (in "a" and "c") might be well adapted to this construction.

f. Chemical treatments dealing only with enhancing fiber surface characteristics for ballistic resistance and not water absorption. Salts compatible with the fibers might be used in preliminary studies.

APPENDIX I

Felt Descriptions and Average V_{50} Values

A. Manufacturing Details

Phase I

(65%/35% Blend)

Sample No.	Batt: Formation	Batt: Weight (oz/yd²)	Batt: Number	No. of Needlings	Felt: Needled Thickness* (in)	Felt: Weight (oz/yd²)	Felt: V_{50}
1.1	P	4	9	9 + 3 tucks	0.33	54.1	922
1.2	P	4	11	11	0.52	54.0	999
1.3	P	4	6 D	6	0.70	54.5	964
1.4	P	4	3 Quad	3	0.72	52.5	1044
1.5	X(17°)	4	13	13 + 2 tucks	0.33	53.8	982
1.6	X(17°)	4	15	15	0.52	51.7	961
1.7	X(17°)	4	8 D	8	0.48	51.0	938
1.8	C	4	12	12	0.57	53.6	968
1.9	C	4	6 D 1 S	7	0.63	52.6	1048
1.10	C	4	3 Quad	3	0.63	52.0	1026
1.11	R	4	1 P 15 R	16	0.62	54.2	1004

* All felts were needled consecutively and, except for 1.1 and 1.5, were pressed to approximately 0.33 inch thickness. 1.1 and 1.5 were needled to thickness.

NOTE: P = parallel, X = cross, C = combination P and X, and R = random batt formation. D = double, S = single, and Quad = quadruple layers of batts.

A. Manufacturing Details (continued)

Phase II

(100% Crimpset Nylon)

	Batt				Felt		
Sample No.	Formation	Weight (oz/yd²)	Number	No. of Needlings	Needled Thickness* (in)	Weight (oz/yd²)	V_{50}
2.1	P	4	16	16	0.59	55.7	1020
2.2	R	4	7 D	7 + 1 tuck	0.78	53.0	1075
2.3	R	4	14	14	0.79	52.7	1056
2.4	X(17°)	4	12	12	0.52	54.0	1118
2.5	X(17°)	8	7	7	0.60	54.0	1014
2.6	X(33°)	8	9	9 + 1 tuck	0.60	57.5	1064
2.7	C(X33° & P)	8	7	7	0.56	54.0	1042
2.8	C(X33° & P)	8	8	8 + 1 tuck	0.65	57.6	1082
(Producers' Virgin Waste 100% Crimpset Nylon)							
2.9	P	8	7	7	0.49	54.0	1004
(99% Nylon, 10% Polypropylene)							
2.10	C(X33° & P)	8	8	8 + 1 tuck	0.60	47.0	1011

* All felts were pressed to approximately 0.33 inch thickness.

NOTE: P = parallel, X = cross, C = combination P and X, R = random. Samples 2.5, 2.6, and 2.7 had 5/8-inch needle penetration on the first 2 passes, 1/2-inch on the next 2 (or on the next 3 if needled and the thickness had not reached 0.40 inch). On the next 2 passes, penetration was 3/8-inch, on the balance 1/4-inch. Sample 2.8 had 210 instead of 277 penetrations per square inch.

A. Manufacturing Details (continued)

Phase III

(100% Crimpset Nylon - 3-in. Fiber*)

Sample	Batt: Formation	Batt: Weight (oz/yd^2)	Batt: Number	No. of Needlings	Felt: Needled Thick. (in.)	Felt: Weight (oz/yd^2)	V_{50}	Variations
3.1	X(33°)	4	11	11	0.52	54.2	1091	
3.2	X(33°)	4	12	12	0.50	52.9	859	90% Nylon, 10% polypropylene
3.3	X(33°)	4	11	11	0.50	56.2	1040	2-inch fiber
3.4	R	4	12	12 + 1 T	0.55	56.0	1007	2-inch fiber
3.5	X(33°)	4	11	11	0.53	53.3	1045	
3.6	X(33°)	4	13	13	0.56	48.6	1105	Indiv. batts preneedled, then laminated
3.7 **	X(33°)	4	11	11	0.52	52.2	1066	Quilon padded on one side, 2 passes 10% solution
3.8 **	X(33°)	4	11	11	0.52	53.0	962	Quilon, impregnated, 10% solution
3.9 **	X(33°)	4	11	11	0.52	53.3	1063	Quilon padded on one side, 5% solution
3.10**	X(33°)	4	11	11	0.52	52.4	987	Quilon, impregnated, 5% solution

* Except Samples 3.2, 3.3, and 3.4. See Variations
** Felts 3.7, 3.8, 3.9, and 3.10 were of the same felt construction, varied only in treatment

NOTE: X = cross, R = random, T = tuck

A. Manufacturing Details (continued)

Phase IV

(100% Crimpset nylon - 3-in Fiber)

Sample No.	Treatment	V_{50}
4.1	Pressed at 310°F	1043
4.2	Pressed at 393°F	1058
4.3	Semi-decated, pressed	1087
4.4	Heat set @ 400°F, pressed	1064
4.5	5% SOD soap, 10% Quilon	839
4.6	5% resin, 10% Quilon	870
4.7	5% Fig soap, 10% Quilon	862
4.8	10% SOD soap, 25% zirconium salts	863

* Felts 4.1 to 4.8 were made with 13 4-oz cross-laid (17°) batts and 13 needlings. They were 53.5 oz/yd^2 inch thick before pressing, 0.33-inch after pressing.

Phase V

(100% Crimpset nylon*)

Sample No.	Treatment	V_{50}
5.1	Untreated	1069
5.2	Semi-decated	1075
5.3	Scoured and semi-decated	1043

* The same felts as 2.4 except 50.6 oz/yd^2 and pressed to approximately 0.33-inch thickness.

NOTE: 50 square yards of sample 5.1 was delivered as required by contract.

B. Comparison of Raw Stock and V_{50} of Blend and Needling Variations

Sample No.	Blend (%)	Number of Needlings	Felt Needled Thickness* (in)	Felt Weight (oz/yd²)	Avg V_{50}
1.2	65/35	11	.520	54.0	999
2.1	100	16	.590	55.7	1020
1.6	65/35	15	.520	51.7	961
2.4	100	12	.520	54.0	1118
1.3	65/35	6	.700	54.5	964
2.9	100 PW	7	.490	54.0	1004
2.1	100	16	.590	55.7	1020
2.9	100 PW	7	.490	54.0	1004
1.7	65/35	8	.480	51.0	938
2.5	100	7	.600	54.0	1014
2.10	90/10	9	.600	47.0	1011

* All felts were pressed to approximately 0.33" thickness.

NOTE: PW = producers' virgin waste

C. Comparison of Batt Form and V_{50} of Batt Type and Needling Variations

Sample No.	Batt Type	Number of Needlings	Felt: Needled Thickness* (in)	Felt: Weight (oz/yd^2)	Felt: Avg V_{50}
2.1	P	16	.590	55.7	1020
2.3	R	14	.780	52.7	1056
2.4	X (17°)	12	.520	54.0	1118
2.5	X (8-oz) (17°)	7	.600	54.0	1014
2.6	X (17°)	10	.600	57.5	1064
2.7	C (33°)	7	.560	54.0	1042

* All felts were pressed to approximately 0.33" thickness.

NOTE: P = parallel, R = random, X = cross, and C = combination

APPENDIX II

Ballistic Test Results

Panel 1.1 (1)

Penetration	
Partial	Complete
929	1012
1003	965
890	888
889	923
890	904

V_{50} = 929

Panel 1.1 (2)

Penetration	
Partial	Complete
902	913
837	927
949	935
846	953
926	959

V_{50} = 915

Panel 1.2 (1)

Penetration	
Partial	Complete
1016	964
961	1023
982	1031
1023	1045
965	1014

V_{50} = 1013

Panel 1.2 (2)

Penetration	
Partial	Complete
988	984
931	1045
988	1001
999	967
940	1003

V_{50} = 985

Panel 1.3 (1)

Penetration	
Partial	Complete
988	1023
907	999
953	1005
929	955
976	1027

V_{50} = 976

Panel 1.3 (2)

Penetration	
Partial	Complete
978	984
967	980
916	951
911	972
892	968

V_{50} = 952

Panel 1.4 (1)

Penetration	
Partial	Complete
997	988
1011	1012
1042	1085
1066	1087
1052	1109

V_{50} = 1045

Panel 1.4 (2)

Penetration	
Partial	Complete
1045	1064
1047	1061
1025	1033
1059	1049
1012	1042

V_{50} = 1044

Panel 1.5 (1)

Penetration	
Partial	Complete
931	1042
940	965
1001	1016
970	1050
972	1025

V_{50} = 990

Panel 1.5 (2)

Penetration	
Partial	Complete
1033	1019
996	1033
940	982
909	955
940	927

V_{50} = 973

Panel 1.6 (1)

Penetration	
Partial	Complete
965	1019
955	990
982	967
968	1055
1027	986

V_{50} = 991

Panel 1.6 (2)

Penetration	
Partial	Complete
974	965
892	967
881	951
879	932
924	947

V_{50} = 931

Panel 1.7 (1)

Penetration	
Partial	Complete
909	972
919	1001
935	1014
980	1005
961	943

$V_{50} = 964$

Panel 1.7 (2)

Penetration	
Partial	Complete
881	976
875	929
854	958
931	892
929	888

$V_{50} = 911$

Panel 1.8 (1)

Penetration	
Partial	Complete
914	997
972	1011
953	994
940	1001
932	1037

$V_{50} = 975$

Panel 1.8 (2)

Penetration	
Partial	Complete
935	1011
931	992
905	992
959	978
911	992

$V_{50} = 961$

Panel 1.9 (1)

Penetration	
Partial	Complete
1014	1049
1035	1057
1037	1035
1001	1090
1080	1105

$V_{50} = 1050$

Panel 1.9 (2)

Penetration	
Partial	Complete
1033	1066
1068	1021
1011	1061
1055	1055
1029	1066

$V_{50} = 1047$

Panel 1.10 (1)

Penetration	
Partial	Complete
1055	1029
1047	1011
1049	994
1066	988
988	990

$V_{50} = 1022$

Panel 1.10 (2)

Penetration	
Partial	Complete
965	1047
986	1061
943	1040
1049	1090
1068	1037

$V_{50} = 1029$

Panel 1.11 (1)

Penetration	
Partial	Complete
972	1071
1019	1005
990	999
958	1070
1003	1008

$V_{50} = 1010$

Panel 1.11 (2)

Penetration	
Partial	Complete
927	1019
922	1029
992	1005
1011	1029
1011	1021

$V_{50} = 997$

Panel 2.1 (1)

Penetration	
Partial	Complete
984	1080
1074	1087
1049	1071
1040	1066
1092	1049

$V_{50} = 1059$

Panel 2.1 (2)

Penetration	
Partial	Complete
967	997
1037	999
980	958
940	972
923	1025

$V_{50} = 980$

Panel 2.2 (1)	
Penetration	
Partial	Complete
1033	1021
1033	1130
1037	1094
1008	1102
1042	1102

V_{50} = 1060

Panel 2.2 (2)	
Penetration	
Partial	Complete
1047	1082
1068	1149
1070	1102
1064	1122
1090	1109

V_{50} = 1090

Panel 2.3 (1)	
Penetration	
Partial	Complete
1012	1068
1029	1071
1042	1096
1045	1096
1109	1135

V_{50} = 1068

Panel 2.3 (2)	
Penetration	
Partial	Complete
1021	1074
980	1090
1029	1070
1021	1092
999	1055

V_{50} = 1043

Panel 2.4 (1)	
Penetration	
Partial	Complete
1080	1156
1092	1122
1059	1130
1077	1154
1100	1149

V_{50} = 1112

Panel 2.4 (2)	
Penetration	
Partial	Complete
1102	1125
1125	1193
1077	1149
1107	1132
1074	1149

V_{50} = 1123

Panel 2.5 (1)	
Penetration	
Partial	Complete
994	1074
996	1045
1029	1068
976	1049
976	1064

V_{50} = 1027

Panel 2.5 (2)	
Penetration	
Partial	Complete
976	1040
1001	999
955	982
1001	1027
999	1033

V_{50} = 1001

Panel 2.6 (1)	
Penetration	
Partial	Complete
1042	1102
1057	1094
1096	1085
1005	1052
1061	1092

V_{50} = 1069

Panel 2.6 (2)	
Penetration	
Partial	Complete
1029	1109
1016	1068
1077	1057
1045	1107
1011	1061

V_{50} = 1058

Panel 2.7 (1)	
Penetration	
Partial	Complete
1037	1068
1023	1040
1029	1125
1064	1021
1001	1092

V_{50} = 1040

Panel 2.7 (2)	
Penetration	
Partial	Complete
1012	1092
996	1085
990	1102
1001	1031
1037	1094

V_{50} = 1044

Panel 2.8 (1)	
Penetration	
Partial	Complete
1042	1070
1064	1100
1064	1143
1090	1122
1052	1064

V_{50} = 1081

Panel 2.8 (2)	
Penetration	
Partial	Complete
1092	1055
1047	1117
1033	1125
1096	1094
1082	1077

V_{50} = 1082

Panel 2.9 (1)	
Penetration	
Partial	Complete
986	1059
990	1029
1016	1061
964	1025
1031	982

V_{50} = 1014

Panel 2.9 (2)	
Penetration	
Partial	Complete
1008	1019
992	1005
988	980
965	1023
964	982

V_{50} = 993

Panel 2.10 (1)	
Penetration	
Partial	Complete
1003	1014
1008	949
976	1023
984	1019
1014	1033

V_{50} = 1002

Panel 2.10 (2)	
Penetration	
Partial	Complete
997	1085
963	1003
1037	1005
1012	1025
1016	1059

V_{50} = 1020

Panel 3.1 (1)	
Penetration	
Partial	Complete
1042	1125
1082	1122
1080	1130
1045	1122
1071	1130

V_{50} = 1095

Panel 3.1 (2)	
Penetration	
Partial	Complete
1090	1087
1031	1080
1035	1102
1125	1152
1094	1087

V_{50} = 1088

Panel 3.2 (1)	
Penetration	
Partial	Complete
862	881
790	888
839	828
789	866
849	854

V_{50} = 845

Panel 3.2 (2)	
Penetration	
Partial	Complete
862	888
857	889
883	909
840	889
869	847

V_{50} = 873

Panel 3.3 (1)	
Penetration	
Partial	Complete
1059	1096
1027	1070
1031	1029
1016	1082
1016	1087

V_{50} = 1051

Panel 3.3 (2)	
Penetration	
Partial	Complete
1037	1059
1027	1042
1035	1042
943	1031
1019	1059

V_{50} = 1029

Panel 3.4 (1)

Penetration	
Partial	Complete
923	1047
972	1008
972	980
959	1027
968	1023

V_{50} = 988

Panel 3.4 (2)

Penetration	
Partial	Complete
968	1042
1027	1055
980	1055
1037	1037
1021	1037

V_{50} = 1026

Panel 3.5 (1)

Penetration	
Partial	Complete
986	1005
1035	1021
963	1071
1047	1068
1085	1085

V_{50} = 1037

Panel 3.5 (2)

Penetration	
Partial	Complete
1003	1100
999	1085
1019	1092
997	1077
1061	1087

V_{50} = 1054

Panel 3.6 (1)

Penetration	
Partial	Complete
1035	1125
1087	1138
1107	1109
1094	1115
1070	1105

V_{50} = 1099

Panel 3.6 (2)

Penetration	
Partial	Complete
1112	1052
1164	1146
1105	1071
1109	1102
1090	1135

V_{50} = 1109

Panel 3.7 (1)

Penetration	
Partial	Complete
1008	1109
1027	1066
1033	1029
1064	1094
1100	1087

V_{50} = 1062

Panel 3.7 (2)

Penetration	
Partial	Complete
1080	1100
1071	1087
1040	1141
1031	1040
1021	1092

V_{50} = 1070

Panel 3.8 (1)

Penetration	
Partial	Complete
970	958
964	935
963	1025
937	1011
935	992

V_{50} = 969

Panel 3.8 (2)

Penetration	
Partial	Complete
935	980
926	974
949	913
924	994
967	984

V_{50} = 955

Panel 3.9 (1)

Penetration	
Partial	Complete
1027	1037
1035	1025
1074	1033
1071	1035
1047	1042

V_{50} = 1043

Panel 3.9 (2)

Penetration	
Partial	Complete
1023	1092
1042	1082
1061	1128
1080	1105
1070	1143

V_{50} = 1083

Panel 3.10 (1)	
Penetration	
Partial	Complete
899	990
896	1021
1001	978
951	1001
1005	1000

V_{50} = 974

Panel 3.10 (2)	
Penetration	
Partial	Complete
959	1003
992	980
945	1057
997	1059
997	1012

V_{50} = 1000

Panel 4.1 (1)	
Penetration	
Partial	Complete
1049	1037
1059	1082
1016	1033
1011	1055
1016	1031

V_{50} = 1039

Panel 4.1 (2)	
Penetration	
Partial	Complete
984	1085
1016	1070
1027	1055
1019	1094
1068	1052

V_{50} = 1047

Panel 4.2 (1)	
Penetration	
Partial	Complete
1049	1100
922	1066
1031	1085
1047	1085
1014	1070

V_{50} = 1054

Panel 4.2 (2)	
Penetration	
Partial	Complete
1027	1071
1047	1085
1066	1068
1023	1025
1087	1122

V_{50} = 1062

Panel 4.3 (1)	
Penetration	
Partial	Complete
1061	1094
1040	1109
1057	1094
1119	1122
1074	1132

V_{50} = 1090

Panel 4.3 (2)	
Penetration	
Partial	Complete
1040	1112
1061	1066
1055	1025
1080	1117
1080	1125

V_{50} = 1076

Panel 4.4 (1)	
Penetration	
Partial	Complete
1008	1059
1033	1080
1057	1100
980	1074
1011	1068

V_{50} = 1047

Panel 4.4 (2)	
Penetration	
Partial	Complete
1052	1125
1074	1090
1021	1077
1023	1143
1092	1122

V_{50} = 1082

Panel 4.5 (1)	
Penetration	
Partial	Complete
830	854
839	871
789	874
828	825
857	855

V_{50} = 842

Panel 4.5 (2)	
Penetration	
Partial	Complete
875	879
775	874
828	828
802	806
815	875

V_{50} = 836

Panel 4.6 (1)	
Penetration	
Partial	Complete
876	846
837	902
810	888
823	876
798	922

V_{50} = 858

Panel 4.6 (2)	
Penetration	
Partial	Complete
854	902
844	875
862	945
873	851
879	949

V_{50} = 883

Panel 4.7 (1)	
Penetration	
Partial	Complete
840	881
773	896
826	868
799	849
825	854

V_{50} = 841

Panel 4.7 (2)	
Penetration	
Partial	Complete
824	931
847	929
871	875
847	883
914	918

V_{50} = 884

Panel 4.8 (1)	
Penetration	
Partial	Complete
824	931
817	889
830	914
813	909
871	869

V_{50} = 867

Panel 4.8 (2)	
Penetration	
Partial	Complete
875	863
814	839
818	883
824	900
849	937

V_{50} = 860

Panel 5.1 (1)	
Penetration	
Partial	Complete
1085	1135
1057	1082
1049	1141
1045	1125
1092	1167

V_{50} = 1098

Panel 5.1 (2)	
Penetration	
Partial	Complete
1074	1061
1019	1066
990	1082
997	1064
996	1059

V_{50} = 1041

Panel 5.2 (1)	
Penetration	
Partial	Complete
1008	1049
1045	1122
1059	1064
1016	1130
1049	1096

V_{50} = 1064

Panel 5.2 (2)	
Penetration	
Partial	Complete
1047	1141
1045	1105
1077	1071
1033	1096
1090	1156

V_{50} = 1086

Panel 5.3 (1)	
Penetration	
Partial	Complete
996	1052
996	1092
1045	1057
999	1040
970	1035

V_{50} = 1028

Panel 5.3 (2)	
Penetration	
Partial	Complete
1008	1092
1040	1061
1012	1077
1005	1128
1042	1112

V_{50} = 1058

Panel 5.4 (1)	
Penetration	
Partial	Complete
1092	1149
1077	1096
1082	1115
1052	1152
1090	1170

V_{50} = 1107

APPENDIX III

Dimensional Changes in Progressive Needlings

A. Phase I

1. Parallel Batts

Felt 1.1

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1	17.0	71	.055
2	18.0	72	.160
3	19.5	72	.260
4	20.0	72	.340
5	21.0	72	.370
6	22.0	72	.400
7	22.5	72	.420
8	23.0	72	.450
9	24.0	72	.470
10 Tuck	24.5	72	.495
11 Tuck	25.0	72	.410
12 Tuck	25.5	72	.330

Wt/yd^2 - 54.1 oz.

Felt 1.2

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1	17.0	68	.080
2	18.0	70	.160
3	19.0	72	.260
4	20.5	72	.370
5	21.0	72	.420
6	21.5	72	.440
7	22.0	72	.450
8	23.0	72	.470
9	24.0	72	.490
10	24.0	72	.500
11	24.0	72	.520

Wt/yd^2 - 54 oz.

Felt 1.3

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1-2	17.0	69	.130
3-4	18.0	70	.310
5-6	19.0	70	.440
7-8	20.0	70	.530
9-10	21.0	70	.630
11-12	22.0	70	.700

Wt/yd^2 - 54.5 oz.

Felt 1.4

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1-4	19.0	65	.340
5-8	20.0	72	.560
9-12	21.0	73	.720

Wt/yd^2 - 52.5 oz.

A. Phase I (continued)

2. Cross-Laid Batts

Felt 1.5

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1	14.5	99	.020
2	15.0	106	.070
3	15.0	112	.190
4	15.0	115	.200
5	15.0	126	.310
6	15.5	127	.370
7	15.5	133	.420
8	16.0	135	.430
9	16.0	135	.460
10	16.0	135	.480
11	16.0	139	.490
12	16.0	140	.500
13	16.0	140	.510
14 Tuck	16.0	140	.400
15 Tuck	16.0	140	.330

Wt/yd^2 - 53.8 oz.

Felt 1.6

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1	15.0	105	.050
2	15.0	109	.070
3	15.0	115	.130
4	15.0	120	.200
5	15.0	125	.255
6	15.0	127	.320
7	15.5	129	.350
8	15.5	132	.370
9	15.5	134	.390
10	15.5	136	.430
11	15.5	139	.450
12	15.5	143	.470
13	15.5	143	.490
14	15.5	143	.510
15	15.5	143	.520

Wt/yd^2 - 51.7 oz.

Felt 1.7

Batt (no.)	Width (in)	Length (in)	Thick. (in)	Batt (no.)	Width (in)	Length (in)	Thick. (in)
1-2	16.0	90	.080	9-10	16.5	110	.360
3-4	16.0	98	.210	11-12	17.0	114	.420
5-6	16.0	102	.280	13-14	17.0	118	.440
7-8	16.0	107	.330	15-16	17.5	121	.480

Wt/yd^2 - 51 oz.

A. Phase I (continued)

3. Combination Batts

Felt 1.8

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1P	15.0	69	.060
2X	15.5	75	.170
3P	15.5	76	.240
4X	15.5	79	.280
5P	16.0	79	.350
6X	17.0	79	.410
7P	17.0	79	.430
8X	17.0	80	.470
9P	17.0	80	.490
10X	17.0	81	.540
11P	17.5	82	.560
12X	17.5	83	.570

Wt/yd^2 - 53.6 oz.

Felt 1.9

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1-2P	17.0	70	.230
3-4X	17.0	80	.300
5-6P	17.5	82	.390
7-8X	18.0	83	.480
9-10P	18.0	84	.570
11-12X	18.0	85	.610
13P	18.0	86	.630

Wt/yd^2 - 52.6 oz.

Felt 1.10

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1-4P	17.0	71	.290
5-8C	18.0	79	.440
9-12S	18.0	79	.630

Wt/yd^2 - 52 oz.

NOTE: X = cross
P = parallel
C = combination
S = single

A. Phase I (continued)

4. Random* Batts

Felt 1.11

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1	17.0	68	.055
2	19.0	68	.160
3	19.0	72	.250
4	19.0	72	.360
5	19.0	72	.410
6	20.0	72	.430
7	20.0	72	.450
8	20.0	72	.470
9	20.0	72	.490
10	22.0	72	.510
11	22.0	72	.530
12	22.0	72	.550
13	22.0	72	.570
14	23.0	72	.580
15	23.0	72	.600
16	23.0	72	.620

Wt/yd^2 - 54.2 oz.

* All but Batt 1, which was parallel

B. Phase II

1. Parallel Batts

Felt 2.1

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1	18.0	68	.030
2	18.0	68	.050
3	22.0	68	.090
4	23.0	68	.110
5	24.0	68	.225
6	25.0	68	.250
7	26.0	68	.290
8	26.0	68	.330
9	27.0	68	.360
10	28.0	68	.440
11	28.0	68	.470
12	28.0	68	.490
13	29.0	68	.530
14	29.0	68	.550
15	29.0	68	.570
16	30.0	68	.590

Wt/yd^2 - 55.7 oz.

Felt 2.9

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	58.0	3-1/2	.110
2	54.0	3-1/2	.210
3	54.0	3-1/2	.300
4	50.0	4	.370
5	50.0	4	.440
6	50.0	4	.470
7	48.0	4	.490

Wt/yd^2 - 54 oz.

B. Phase II (continued)

2. Cross-Laid Batts

Felt 2.4

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	61.0	3	.030
2	54.0	3	.090
3	54.0	3	.150
4	54.0	3-1/2	.230
5	49.0	3-1/2	.290
6	48.0	3-1/2	.330
7	48.0	3-1/2	.380
8	48.0	3-1/2	.400
9	48.0	3-1/2	.440
10	45.0	3-1/2	.500
11	45.0	3-1/2	.500
12	45.0	3-1/2	.520

Wt/yd^2 - 54 oz.

Felt 2.5

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	59.0	6	.110
2	57.0	3-1/2	.240
3	54.0	4-1/2	.300
4	50.0	4-1/2	.400
5	50.0	4-1/2	.460
6	50.0	4-1/2	.520
7	50.0	4-1/2	.600

Wt/yd^2 - 54 oz.

Felt 2.6

Batt (no.)	Width (in)	Length (yd)	Thick. (in)	Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	59.0	2-1/2	.070	6	48.0	3	.400
2	56.0	2-3/4	.140	7	48.0	3	.450
3	54.0	2-3/4	.210	8	48.0	3	.510
4	50.0	3	.280	9	45.0	4	.600
5	48.0	3	.340	10T	45.0	4	.600

Wt/yd^2 - 57.5 oz.

B. Phase II (continued)

3. Combination Batts

Felt 2.7

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1X	59.0	2-1/2	.070
2P	59.0	2-1/2	.150
3X	58.0	3	.240
4P	55.0	3	.340
5X	54.0	3	.410
6P	54.0	3	.490
7X	54.0	3	.560

Wt/yd^2 - 54 oz.

Felt 2.8

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1X	58.0	2-1/4	.050
2P	58.0	2-1/2	.140
3X	56.0	2-1/2	.240
4P	56.0	2-1/2	.340
5X	56.0	2-1/2	.440
6P	56.0	2-1/2	.510
7X	56.0	2-1/2	.600
8P	56.0	2-1/2	.680
9T	56.0	2-1/2	.650

Wt/yd^2 - 57.6 oz.

Felt 2.10

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1X	59.0	2	.050
2P	54.0	2-1/2	.130
3X	54.0	2-1/2	.230
4P	53.0	2-1/2	.300
5X	53.0	2-1/2	.400
6P	53.0	2-1/2	.520
7X	53.0	2-1/2	.610
8S	53.0	2-1/2	.700
9T	53.0	2-1/2	.600

Wt/yd^2 - 47 oz.

P = parallel
X = cross
T = tuck
S = single

B. Phase II (continued)

4. Random Batts

Felt 2.2

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1-2	15.0	75	.230
3-4	15.0	78	.480
5-6	15.0	78	.630
7-8	16.0	79	.720
9-10	16.0	81	.800
11-12	16.0	82	.840
13-14	16.0	83	.970
15 Tuck	16.0	83	.780

Wt/yd^2 - 53 oz.

Felt 2.3

Batt (no.)	Width (in)	Length (in)	Thick. (in)
1	15.0	86	.060
2	15.0	88	.140
3	15.0	88	.230
4	15.0	88	.390
5	15.5	89	.500
6	15.5	89	.540
7	15.5	89	.590
8	15.5	90	.620
9	15.5	90	.650
10	15.5	91	.660
11	16.0	91	.670
12	16.0	91	.710
13	16.0	92	.720
14	16.0	93	.790

Wt/yd^2 - 52.7 oz.

C. Phase III

1. Cross-Laid Batts

Felts 3.1 and 3.7 through 3.10

Batt	Width	Length	Thick.
1	58.0	8	.060
2	48.0	10	.110
3	48.0	12	.170
4	48.0	12	.210
5	48.0	12	.270
6	48.0	12	.330
7	48.0	12	.380
8	48.0	12	.430
9	48.0	12	.470
10	48.0	13	.500
11	48.0	13-1/2	.520

Wt/yd^2

3.1	54.2 oz.
3.7	52.2 oz.
3.8	53.0 oz.
3.9	53.3 oz.
3.10	52.4 oz.

2. Nylon/Propylene Batts

Felt 3.2

Batt	Width	Length	Thick.
1	60.0	5	.060
2	57.0	5-1/2	.120
3	55.0	5	.200
4	54.0	5	.250
5	54.0	5	.290
6	54.0	5	.340
7	54.0	5	.370
8	54.0	5	.400
9	54.0	5	.420
10	54.0	5	.450
11	54.0	5	.470
12	54.0	5	.500

Wt/yd^2 - 52.9 oz.

C. Phase III (continued)

3. Two-Inch-Fiber Nylon Batts

Felt 3.3

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	61.0	4	.070
2	54.0	5	.150
3	53.0	6	.190
4	52.0	6	.250
5	52.0	6	.320
6	52.0	6	.350
7	52.0	6	.400
8	52.0	6	.440
9	52.0	6	.460
10	52.0	7-1/2	.490
11	52.0	7-1/2	.500

Wt/yd^2 - 56.2 oz.

4. Two-Inch-Fiber Nylon Random Batts

Felt 3.4

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	37.0	2-3/4	.080
2	36.0	3	.160
3	35.0	3	.225
4	35.0	3	.290
5	34.0	3	.350
6	34.0	3	.390
7	34.0	3	.420
8	34.0	3	.450
9	34.0	3	.475
10	34.0	3	.500
11	34.0	3	.530
12	34.0	3	.585
Tuck	34.0	3	.550

Wt/yd^2 - 56.0 oz.

C. Phase III (continued)

Felt 3.5

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	58.0	2-1/2	.080
2	54.0	3	.160
3	51.0	3	.240
4	50.0	3	.310
5	49.0	3	.360
6	48.0	3	.380
7	48.0	3	.430
8	48.0	3	.460
9	48.0	3	.480
10	48.0	3	.510
11	48.0	3	.530

Wt/yd^2 - 53.3 oz.

Felt 3.6

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	60.0	26	.080
1*	56.0	2	.690
Tuck	52.0	2	.560

Wt/yd^2 - 48.6 oz.

*Batt No. 1 was cut into 13 two-yard (4-oz) pieces which were combined in one needling.

D. Phase IV

Felt 4.1

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	75.0	20	.060
2	70.0	24	.130
3	65.0	26	.230
4	61.0	27	.300
5	61.0	27	.370
6	61.0	27	.420
7	61.0	27	.460
8	61.0	28	.480
9	59.0	30	.500
10	59.0	29	.520
11	58.0	28	.540
12	56.0	29	.580
13	54.0	30	.540

Wt/yd^2 - 53.5 oz.

E. Phase V

Felt 5.1

Batt (no.)	Width (in)	Length (yd)	Thick. (in)
1	75.0	35	.050
2	70.0	41	.175
3	65.0	43	.215
4	62.0	45	.300
5	60.0	46	.350
6	59.0	48	.400
7	58.0	48	.450
8	56.0	50	.480
9	55.0	51	.500
10	54.0	51	.540
11	54.0	52	.570
12	54.0	55	.525

Wt/yd^2 - 50.6 oz.

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13. ABSTRACT

Felts made from high tenacity nylon 6,6 (industrial quality), bright, 6-denier filament, three-inch staple, crimpset fiber were found to be the most satisfactory in ballistic resistance, uniformity, and ease of processing among the group studied. Batts that were cross-laid proved to be superior to the parallel-laid batts and equal to a combination of straight- and cross-laid batts. The best felt, from the standpoint of both ballistic resistance and dimensional stability, was produced by needling 4-ounce batts alternately on each side, with 277 penetrations per square inch and a half-inch needle penetration, followed by flat-bed pressing (using 0.29-in spacer bars at 310°F for 2-1/2 min) to attain the desired thickness.

Producer's virgin waste of the same high tenacity nylon 6,6 appeared to be promising although the test results were inconclusive. These and other fibers, also various processing methods and treatments, are discussed.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Measurement	8					
Ballistics	9					
Resistance	9					
Nylon	9,4					
Felt	9,4					
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